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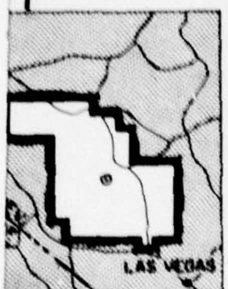

NEVADA TEST SITE
MAY-OCTOBER 1957

Project 39.3

THERMAL RADIATION MEASUREMENTS (PARTS I AND II)

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This is a preliminary report based on all data available at the close of this project's participation in Operation PLUMBBOB. The contents of this report are subject to change upon completion of evaluation for the final report. This preliminary report will be superseded by the publication of the final (WT) report. Conclusions and recommendations drawn herein, if any, are therefore tentative. The work is reported at this early time to provide early test results to those concerned with the effects of nuclear weapons and to provide for an interchange of information between projects for the preparation of final reports.

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Operation PLUMBBOB Preliminary Report

Project 39.3

THERMAL RADIATION MEASUREMENTS (PARTS I AND II)

By

A. L. Greig and Herman E. Pearse, MD

Approved by: R. L. Corsbie
Director, Program 39
Director, Civil Effects Test Group

Division of Biology and Medicine
U. S. Atomic Energy Commission

January 1958

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ABSTRACT

Part I: The objective of Part I of Project 39.3 was to measure transient air temperatures at selected locations in the blast-biology underground shelter in Area 1 for shot Galileo, Operation Plumbbob. The procedure used in making these measurements was similar to those techniques used by the Naval Radiological Defense Laboratory in making air-temperature measurements in Operation Teapot, 1955. No data were obtained from this shot owing to failure of one recorder at zero time. The record from the second duplicate recorder and sensing devices was lost in the developing process because of failure to anticipate an overexposure of the film to the high prompt-gamma emission from the detonation; also it is possible that this recorder stopped before zero time. Evaluation of the equipment used shows that, if equipment is modified or redesigned to be compatible with now known conditions, measurements of rapidly changing air temperatures can be made at distances in close proximity to Ground Zero.

Part II: The objective of Part II of Project 39.3 was to evaluate thermal burns from a nuclear explosion on biological receivers in a shelter. Eight Chester White pigs were used as test animals.

One pig in the entrance and one about 3 ft inside the door received severe burns. These burns were carbonized on the surface and caused transepidermal damage with up to 0.3 mm penetration into the dermis.

Animals away from the entrance and those in the slow fill side received no burns. The possible sources of this damaging thermal energy are discussed.

[redacted]

PREFACE

On past tests there has been evidence that damaging thermal radiation has been present inside shelters exposed to nuclear detonations. The phenomena of its occurrence in the shelters is not understood.

At the Operation Plumbbob Biomedical Test Planning and Screening Committee meetings, a project was approved to measure the air temperature within a shelter in which several potential burn receivers (biological) would be exposed.

The Naval Radiological Defense Laboratory undertook the responsibility for instrumenting the shelter and recording the measurements. The University of Rochester in conjunction with the Division of Biology and Medicine, AEC, undertook the responsibility for providing the animals and the medical personnel necessary for the biomedical portion of the project.

This report is presented in two parts. Part I includes the instrumentation and air-temperature measurements; Part II includes the placement of animals and evaluation of the thermal burns received by them.

[redacted]

CONTENTS

ILLUSTRATIONS

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PART I

TIME-TEMPERATURE HISTORY OF AIR IN THE BLAST-BIOLOGY SHELTER FOLLOWING A NUCLEAR DETONATION

By
A. L. Greig

U. S. Naval Radiological Defense Laboratory

[redacted]

Chapter 1

INTRODUCTION

Project 39.3 (Part I) was proposed as a field test to determine air temperatures within an underground shelter in the vicinity of a nuclear detonation. On one shot of Operation Teapot animals and harnesses in a similar shelter showed evidence of burns. This project was initiated in an attempt to correlate burns with test conditions.

1.1 OBJECTIVES

The principal objective was to obtain air-temperature data, its temporal history, and the variation of temporal history at selected locations within the underground blast-biology shelter in the vicinity of a nuclear detonation prior to, during, and after shock arrival. These measurements would then be available for correlation with thermal burns on various animals located within the shelter.

1.2 BACKGROUND

There was no exact explanation for the thermal burns that occurred on the animals during Operation Teapot. One theory indicated that the animals were burned by reflected thermal radiation released at the time of detonation. Another theory was that the burns might have been due to simple exposure in extremely hot air. The hot air could be caused by the adiabatic compression of air at constant volume as a consequence of the blast over-pressure. The general gas law, $P/P_o = T/T_o$, could then be used to predict the temperature, T, as a function of the pressure in each of the rooms in the shelter. Assuming an initial temperature (T_o) of 300°K and an initial pressure of 15 psia, an overpressure of 25 psi would give a transient temperature of 800°K.

By establishing the time relation or difference between the peak time of the thermal-radiation pulse, the peak time of maximum air temperature, and the time of arrival of the shock wave, one might be able to attribute the air-temperature rise and/or thermal burns to either reflected direct radiation and/or to the adiabatic compression of the air at constant volume.

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Chapter 2

PROCEDURE

2.1 SHOT PARTICIPATION

Air-temperature measurements were made in the blast-biology shelter in Yucca Flat, Area 1, 1050 ft south of GZ on shot Galileo.

2.2 INSTRUMENTATION

For the measurement of air temperature,[1] a high-velocity air thermocouple (HiVat) was used. This consisted essentially of a 1-mil-diameter platinum-platinum (90 per cent) rhodium (10 per cent) thermocouple mounted on two brass cylinders (cold junctions) attached to, but electrically insulated from, each other by means of a mica disk. The thermocouple junction was placed in the center of a hole drilled through the axis of the brass cold junctions. When air was aspirated through this hole, the thermocouple was exposed to the heated air flowing past the thermocouple junction. In order to insulate the brass cylinders from the heated air, pyrex-glass tubes were inserted in the holes of each cylinder, and the air was drawn through the insulating tubes. Compressed-air aspirators are used to draw air through the HiVat. A more complete description of the HiVat can be found in reference 1.

Two standard Naval Radiological Defense Laboratory Mark IV radiometers were connected to the Heiland oscillographic recorders in an effort to establish a known zero time and to determine the shape and peak time of maximum irradiance of the thermal emission from the detonation.

In addition, one copper-constantan thermocouple, with an ice bath as a reference cold junction, was used to determine the ambient temperature of the shelter prior to shot time. This temperature will allow us to correct our room-temperature cold junctions to a standard reference temperature.

[redacted]

Laboratory calibrations have shown that the melting point of gold (1063°C) can be determined to within about 2 per cent with the HiVat. It has also been determined that the difference between the temperature of the air before entering the HiVat as compared with that measured in the HiVat is relatively small. For example, over a 1000°C range the cooling was 1 to 4 per cent, this being practically within the experimental error.[1]

The optimum air flow rate was found to be between 0.6 and 1.0 cu ft/min, that is, reproducible results are obtained for flow rates within this range. For the purposes of this experiment, where air temperature is to be recorded during the pressure build-up period as well as prior to arrival of the shock wave, the flow of air was adjusted to 1 cu ft/min. It was felt that during the pressure build-up phase the prime moving air flowing through the aspirator would tend to reduce in velocity as it exhausted into an atmosphere of above ambient pressure. As the velocity of the prime moving air was reduced, the flow of air to be measured would also be reduced. If the flow of sampled air were reduced to a rate of less than 0.6 cu ft/min, the accuracy of the air temperature would be reduced.

Therefore, the prime moving air delivery system was adjusted to provide a sample air flow of 1.0 cu ft/min with a prime moving air pressure of 100 psi. To simulate the flow of sampled air when the exhausted prime moving air discharged into an atmosphere 25 psi above ambient pressure, the air delivery pressure was reduced from a normal 100 psi to 75 psi. The flow of sampled air was reduced but only to a value of 0.7 cu ft/min. This flow rate is still within the optimum range of flow for reproducible results.[1]

Since the field operation required the use of Heiland oscillographic recorders, it was necessary to determine the change in sensitivity of the recorder system due to change in resistance of thermocouple as the temperature of the latter changes. For the input circuits used with the Heiland recorders, it has been determined that the sensitivity change from ambient temperature to 1000°C is about 6 or 7 per cent.

In view of the above calibrations and corrections to be applied to the temperature measured by the HiVat, it is safe to state that the results should thus be accurate to better than 10 per cent.

2.3 INSTALLATION

Twelve high-velocity air-temperature measuring instruments (HiVats) were installed at six specified locations in the blast-biology underground shelter at a height of 4 ft above floor level, three stations being located in each of two rooms. Each station was equipped with two HiVats. Data from each HiVat were recorded on a channel of a Heiland oscillographic recorder. The recording for each station was divided

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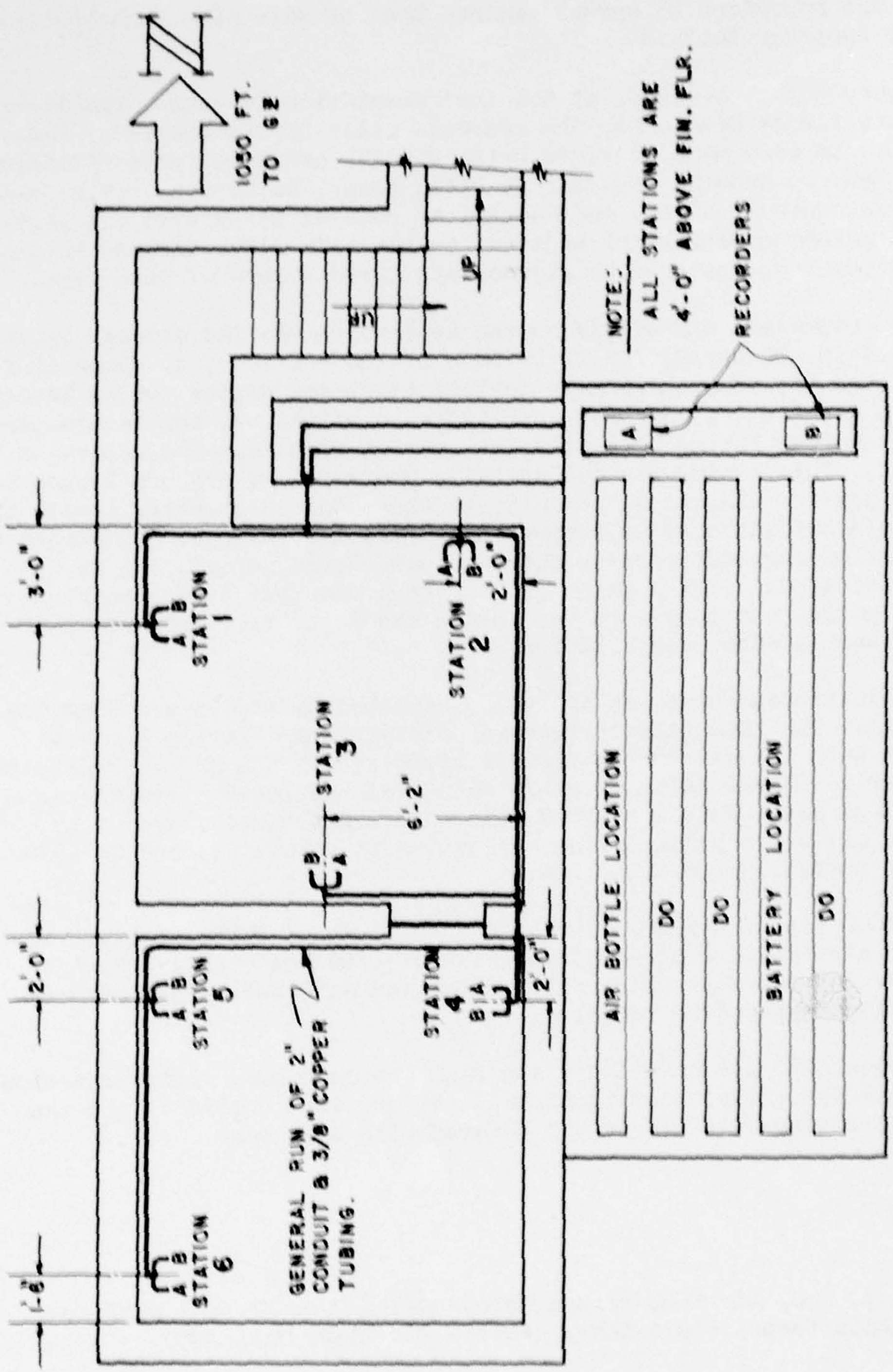

Fig. 2.1--Instrumentation lay-out, blast-biology shelter.

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between two recorders to ensure against loss of data as a consequence of possible recorder failure.

Figure 2.1 is a sketch of the instrumentation lay-out. The instruments were firmly mounted to the concrete walls of the shelter. Instrument supports were made of rigid 2-in. conduit and 2-in. pipe fittings. Air bottles, recorders, recorder junction boxes, batteries, compressed-air-bottle control valves, and electrical control boxes were all located in the concrete entrenchment adjacent to the main blast-biology shelter. This equipment was covered by plywood and three layers of sand bags.

The compressed air supply to the aspirators was fed through individual 3/8-in.-OD copper tubing to each of the stations, as shown in Fig. 2.1. At the top of each station installation, the copper tubing branched through a tee fitting and then supplied each of the two aspirators per station. Rubber tubing connected the suction pipe from the aspirator to the HiVat. This tubing was mechanically protected by a short length of flexible 1/2-in. electrical conduit; it was then fed directly inside the 2-in. rigid conduit used to support the HiVat instruments. To minimize the effect of magnetic pick-up due to electromagnetic emission at time of detonation, all signal pairs of wire from the HiVats were twisted, shielded pairs, and they were run inside the 2-in. rigid conduit that serviced each station installation.

All instrumentation was set to be actuated by the -5 sec EG&G timing signal. The EG&G relay triggered holding relays in the junction boxes for both the air-bottle control circuits and the Heiland recorder power supply. These holding relays energized the power circuits for a period of 30 sec. This was ample time to bring the recorders up to speed, to allow the prime moving air system to stabilize, and to allow 25 sec of postshot recording time.

At 1800 hrs on D-2 day, the -5 sec EG&G signal successfully triggered the air-bottle control circuitry. At 1800 hrs on D-1 day, the full-power dry-run was successfully completed with both the recorders and all HiVats operating properly.

Between 2200 hrs on D-1 day and 0100 hrs on D day, instrumentation was checked out, final electrical calibrations were recorded, and the instrument shelter was closed and covered with sand bags.

REFERENCE

1. E. C. Y. Inn, Air-temperature Measurements Over Several Surfaces, Operation Teapot Preliminary Report, ITR-1149, May, 1955.

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Chapter 3

RESULTS

3.1 RESULTS FROM RECORDER A

At approximately H + $3\frac{1}{2}$ hrs one recorder was recovered from the instrument shelter. The second recorder was left in the shelter because of the high level of residual radiation in the area at this time. The Rad-Safe monitor would not permit the recovery party to remain in the active area any longer than 6 or 7 min. The recorder, with film intact, was brought to the NRDL processing trailer at Indian Springs Air Force Base. The recorder, with switches untouched, was connected to a 24-volt battery. The recorder immediately ran and appeared to be mechanically undamaged. The film was removed and processed in a manner typical of development for all other microfile film used prior to this event in Operation Plumbbob.

When the developed film was examined, it was obvious that the film had been overexposed to an irradiation of extremely high flux density. The contrast ratio between the record trace image and the film background was so low that it was impossible to distinguish one from the other. Subsequent calculations indicated that the film had received a dosage $1\frac{1}{2}$ times that which controlled exposures in the laboratory deemed tolerable. Faint images of preshot calibrations for two of the eight channels of information used were barely discernable, but no other useful data could be read from this record.

3.2 RESULTS FROM RECORDER B

After it was recognized that the film from recorder A had been overexposed to a high radiation field, the film from recorder B was returned to the NRDL for special developing and processing. There it was determined that by developing several different sections of the film for periods of from 1 to 4 min a continuous and readable record could be made. The film was developed, and all channels of information and time lines could be readily distinguished from the badly fogged background.

However, owing to an as yet unexplained cause, recorder B apparently stopped just at zero time. No information is available beyond this point. The record showed all preshot calibrations for each channel of information. There is indication that the recorder started with the preshot EG&G signal and continued to run just until zero time. At this point the recorder ceased to function without apparent reason.

Similar failures of the recording system have happened at previous times in other operations when recording stations have been close to GZ.[1,2] These failings have not been reproducible, nor have they been predictable. The effect of shock on the recorder would not disturb the deflection of the trace appreciably. Failure of a timing signal in this case seems unlikely since the air-bottle circuitry appeared to function satisfactorily. In the past, an unsupported theory has been presented that possibly the electromagnetic emission at the time of detonation disturbs the driving magnetic flux of the recorder motor. Unlikely as this seems, several Heiland recorders have failed just at zero time for no apparent reason.[1,2] No satisfactory explanation can be offered at this time for the failure of recorder B.

The Heiland recorder used for testing a similar system on Turk shot, Operation Teapot, gave usable data through the entire thermal pulse and long after shock arrival. The recorder was located nearer a nuclear detonation of larger yield. The only difference in the two cases was the fact that the Turk shot recorder was located in a deep underground shelter and the Galileo shot recorder was located in a shallow underground shelter.

3.3 PERFORMANCE OF THE HIVATS

On D+3 day, a recovery party recovered all HiVats from the blast-biology shelter. Postshot photographs were taken of all HiVat instrument stations. Physical examination of the instruments indicated that all HiVats functioned in the proper manner; that is, all pyrex-glass intake nozzles were internally coated with dust. Many of the thermocouple wires had what appeared to be a fuzz, or possibly minute animal hairs, adhering to the wire. This indicated that the HiVats were definitely aspirating air through the intake nozzles during the event.

An electrical continuity check of each instrument indicated that the thermocouple circuit was open in the HiVats at the following stations: 1-B, 2-B, 5-A, and 6-A. Location of these stations is shown in Fig. 2.1. The other eight instruments within the shelter were undamaged.

The failure of the above thermocouples may have been due to particles of sand impinging on the 1-mil-diameter wire at high velocity (120 ft/sec) and breaking the wire. Possibly the intake pyrex-glass nozzle was displaced by the shock wave, severing the thermocouple wire. It seems unlikely that the thermocouple wire burned out since thermocouples of this type have been successfully used to measure temperatures as high as 1760°C.

A general observation can be made from the appearance of equipment within the shelter. All instrumentation within the room closest to the blast was heavily coated with dust. The room farthest from the blast, with the specially designed escape hatch, was less dusty. This may be an indication that the blast effect was not as great in one room as in the other. Also, the appearance of dust inside the HiVats would lead one to suspect the reliability of any air-temperature measurements made after the time of shock arrival. Any spurious changes in the temperature records would be difficult to distinguish between true sharp changes in actual air temperature and sharp deflection changes due to the thermocouples being struck by hot particles of sand or dust.

3.4 EFFECT OF SHOCK ON EQUIPMENT

The overpressure within the shelter did not appear to affect the instrumentation to any great extent. Only one instrument station appeared to be affected only slightly. This was Station 1, located in the most exposed position to blast. The bottom tee of the instrument mount had started to unscrew when it was subjected to the blast overpressure. The rotation was only approximately 10 deg; so this was not considered detrimental.

When the recovery party removed the sand bags from the recorder section of the ground-level instrument shelter, it was found that sand had partially filled the concrete entrenchment. Possibly either the negative phase of the shock wave or an air-foil action of the positive phase had lifted and dropped the plywood base and sand bags. During the interval of rising and falling intact to the concrete entrenchment, a great deal of sand had been allowed to enter the shelter. This made physical removal of the recorders quite difficult. However, subsequent examination of the recorders and junction boxes revealed that no damage had occurred. As was noted earlier, the recorders ran properly after removal from the shelter. Also, since the air system was given a post-shot field check, it can be said that the air system still functioned.

REFERENCES

1. E. C. Y. Inn, Air-temperature Measurements Over Several Surfaces, Operation Teapot Preliminary Report, ITR-1149, May, 1955.
2. R. W. Hillendahl and F. I. Laughridge, Basic Thermal-radiation Measurements, Operation Teapot Report, WT-1146, May 1957.

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Chapter 4

CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

4.1 CONCLUSIONS

Since records of the air temperature within the shelter were not obtained, no data can be presented.

Some animals received burns. The cause of these burns has not been established, and it is regrettable that no information relating to air-temperature histories can be presented. Therefore, at this time, no factual correlation can be made between the animal burns and the transient air temperatures within the shelter.

4.2 DISCUSSION

The use of HiVats for measuring air temperatures within a shelter for the period shortly after detonation of a nuclear weapon leaves a great deal to be desired. For instance, the reliability of the recording system is not very high (owing to an unexplained phenomena that happens at zero time, causing the recorders to occasionally cease operating). The effect of the shock wave as it passes the intake nozzle at approximately sonic velocities is a phenomena that has not been fully studied. What actually transpires is not known. Does the sampled air flow decrease or increase beyond the reproducible limits for accuracy in the instrument? The effect of hot particles other than air striking the thermocouple can also possibly introduce errors in the evaluation of data. And finally, the volume of air that is measured is small in comparison to room volume. Prior to shock arrival, only about 0.003 cu ft of air is measured since the sampling rate is 1 cu ft/min. This sampled volume of air, when compared to a total room volume of over 1100 cu ft, seems to be a very small proportion. It hardly seems possible that the temperature of the air would remain uniform without temperature gradients for any given finite instant. Even when six instruments per room are used, measurements in these places may not be a true indication of representative air temperatures in the rooms of the shelter.

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4.3 RECOMMENDATIONS

It is recommended that, if attempts to measure transient air temperatures in close proximity to GZ are made again, more time be allowed for preparation of the experiment. Points which should receive more attention are as follows:

1. A more adequate shelter should be provided to protect the recording system.
2. If similar temperature-sensing devices (HiVats) are to be used, a thorough study should be made to determine operating characteristics under shock-wave conditions.
3. Possibly an entirely new air-temperature-sensing device should be designed in full regard of all anticipated operating conditions.
4. Investigation of a more reliable means of recording should be initiated.
5. A means should be provided to enable investigators to sample a larger proportion of the total volume of air under observation.
6. Radiometers or even photronic cells could be installed inside the shelter to measure directly the reflected thermal radiation, if any, within the shelter.

It is obvious that, if the above points are to be considered and if solutions to the many problems are to be developed, a great deal of time and effort will have to be spent before taking such a project to the field.

It is recommended that studies be conducted relative to the electromagnetic effects on equipment, especially d-c motors. Sandia Corporation has measured extremely high transient electric currents. These currents, no doubt, are accompanied by high magnetic fields. A clear understanding of this problem would lead to a solution that could either eliminate or minimize the effect on recording equipment.

PART II

BIOLOGICAL EVALUATION OF THERMAL BURNS
WITHIN SHELTERS

By
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University of Rochester School of Medicine and Dentistry

Chapter 5

INTRODUCTION

In their work on blast biology, investigators from the Lovelace Foundation, directed by Dr. C. S. White,[1] found that animals within shelters sustained thermal burns. These animals were well shielded from any direct thermal radiation from the fireball of the atomic explosion. This phenomena was puzzling and immediately recalled the fact that some Japanese who were within caves beneath the prison at Nagasaki sustained thermal burns despite the fact that they could not have been exposed to direct, radiant thermal energy.

There has been much discussion of the mechanism causing thermal burns within shelters. The mechanism has a direct bearing upon the method of experimental attack on the problem; therefore it is worth while to list the various factors that have been considered. These are as follows:

1. The precursor wave of heated air may be driven into the openings of the shelter by the shock front. It is significant to observe that the burns are always most severe near an entrance and are oriented toward it. In burns sustained away from the apertures, the animals were in a position to receive a stream of air from the entrance. It is noteworthy that at shot Kepler pressure readings showed no precursor wave and there were no burns; whereas at shot Galileo a precursor wave was recorded and the animals within a shelter were burned. This may be coincidence.

2. Another source of hot air is from the ignition of flammable material on the surface of the ground in front of the shelter by the thermal pulse. This hot air is then forced into the shelter by the blast wave. This effect could be increased by the heating and "pop-corning" of the soil itself. That a flammable surface may raise the level of air temperature is suggested by the measurements of Inn[2] who obtained higher readings beyond plots of dried leaves.

3. Molecular excitation of the constituents of the air has been suggested as a source of the thermal energy causing the burns. At present this can neither be proven nor denied.

4. Hot dust particles that are blown into the shelter might cause contact burns or, because of their heat capacity, might transfer thermal energy to the surrounding air. Localized contact burns from large particles have not been observed, but the particle size is ordinarily small. If a layer of small hot dust particles caused burns by contact, evidence of this should be seen in the form of a thicker cake of dust on singed hair or on burned bare skin. This has not been observed. If heating of the air occurs from dust, it does not produce a generalized hyperthermia because the effect is directional in the path of the greatest air movement.

5. The "ram effect" of the shock front causing compression in the confined space of the shelter was thought of, but, from the pressure changes that have been observed, it was considered unlikely and was discarded.

6. Reflection, reradiation, and scattering in the shelter entryways of the radiant thermal energy from the fireball is a possibility that should be evaluated. The level of thermal energy outside the shelter is high. At shot Galileo it was estimated to be about 230 cal/cm^2 at the outside entrance. The elevation of the weapon gives a line of sight onto the wall at the first landing of the stairway and onto the rear wall of the shaft. If only such a small fraction as 5 per cent of the radiant thermal pulse were directed into the shelter by scattering, it would be sufficient to cause the burns observed. Proper assessment of this factor requires calorimetric measurement of the radiant thermal energy entering the shelter.

7. Evaluation of all the above possibilities of thermal energy getting into a shelter leads to the conclusion that the weight of evidence favors hot air as the most probable cause of the burns.

<u>REFERENCES</u>

1. C. S. White et al., Effects of Overpressures on Biological Systems, Operation Teapot Preliminary Report, ITR-1179.
2. E. C. Y. Inn, Air-temperature Measurement over Several Surfaces, Operation Teapot Preliminary Report, ITR-1149.

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Chapter 6

PROCEDURE

6.1 INSTRUMENTATION

If air-temperature measurements could be correlated with pressure readings, it would make the biological effects more meaningful since it would give an indication of the time-temperature history. The difficulty was to secure suitable instruments in the time available. Previously instrumentation for air-temperature measurements of the type required has been designed by E. F. Cox of the Sandia Corporation, Harold Stewart of the Naval Research Laboratory, W. L. Fons of the California Forest and Range Experiment Station, and by E. C. Y. Inn of the Naval Radiological Defense Laboratory. Only that of Inn was operational and available. It was the property of Armed Forces Special Weapons Project, who consented to its use. Members of the staff of NRDL agreed to install and operate this equipment in a shelter prepared for Program 33. Their results are given in Part I of this report.

In addition, pieces of thermal-sensitive paper were attached to the wall of the shelter in conjunction with placement of the pigs. These showed no change in color from heat.

6.2 BIOLOGICAL STUDIES

The Chester White pig, which has a skin very similar to that of man, is the most sensitive and best documented biological receiver for thermal-burn studies. Thousands of controlled laboratory observations have been made on this animal; therefore the calories per square centimeter required to produce any given degree of burn severity are known, within the limits of accuracy imposed by an unknown exposure time. It was desired that the Atomic Energy Project of the University of Rochester provide and place Chester White pigs in the shelter that was instrumented for the thermal measurements. This was made possible by the assistance and cooperation of the members of Program 33.

6.2.1 Animals Used

Young, healthy Chester White pigs weighing between 25 to 30 pounds were procured, inoculated, and shipped from Rochester, N. Y. They arrived in good condition without evidence of sickness from shipping.

On D-1 day the hair on both sides of their bodies was removed with electric clippers having a No. 40 head.

6.2.2 Restraints Used

It was not planned to anesthetize the animals; thus restraint was needed to position them. This was of two types. A web strap harness was made which buckled onto the animal. To this was attached lengths of light chain that were fastened to the structure to give a 6-point suspension. The other method was by use of a 2-ft-long cage of strong steel-wire mesh having a diamond-shaped aperture of about 1 in. These had heavy supports welded to them, which in turn were bolted to the floor. They were designed and fabricated by members of Program 33.

6.2.3 Animal Placement

Figure 6.1 is a plan of the shelter showing the position of each animal within it. The walls were 8 ft high, each room was 12 ft square, and the ceiling was 5 ft below grade. A steel door frame was bedded into the concrete at the bottom of the steps, but no door was used. An escape shaft emerged from the ceiling of the inner room, and, since its sectional area was smaller than the outside door, this room was called the "slow-fill" side, and the room with the door was termed the "fast-fill" side. A closed steel door separated the two rooms.

Consideration was given to placing an animal on the stair landing at the position marked X, but it appeared that the line of sight from the weapon was such that direct thermal radiation would be received here which would be greater by a factor of 20 than that necessary to produce a severe, carbonized burn. Clearly, no useful information could have been obtained from such an exposure; so this position was not used.

Animal 7 was put in a steel mesh cage against the wall of the landing at the foot of the steps outside the door frame. It was realized that this animal would receive severe blast effects in this position, but it was hoped that if it survived this a useful comparison would be obtained with the animal inside the door. The latter pig, No. 5, was positioned facing the open door in a wire mesh cage placed on the floor 2 ft from the door frame. Since the cage was 2 ft long, the body of the animal was centered about 3 ft from the door. Pigs 1 and 3 were on a table in the center of the room which was 15 in. above the floor.

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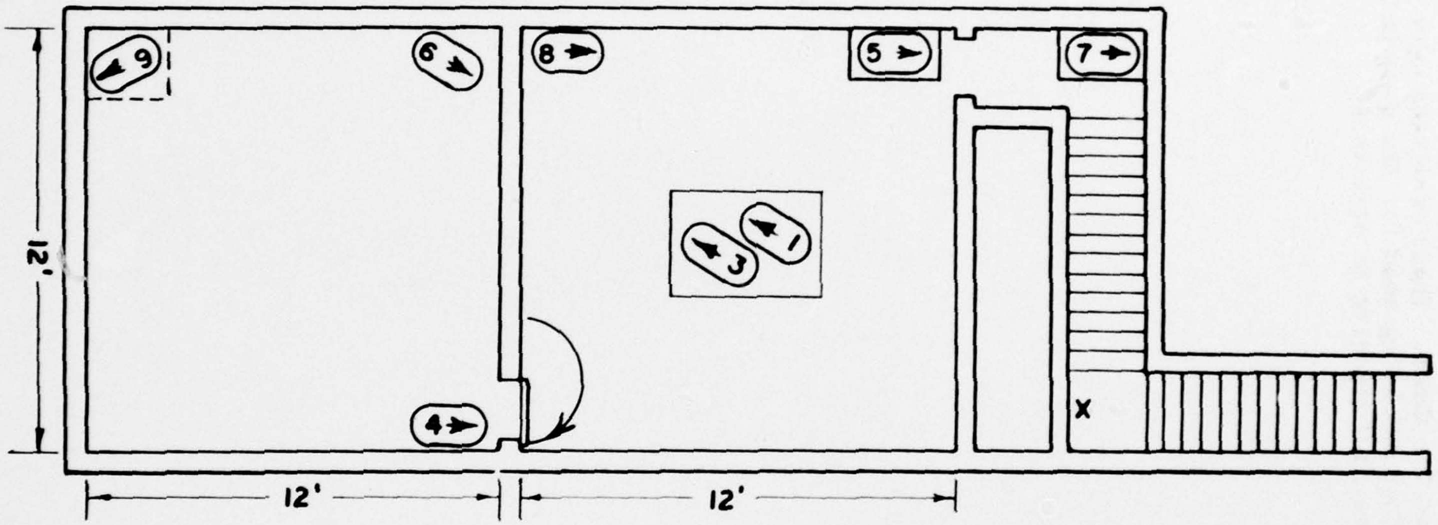

Fig. 6.1--Floor plan of the shelter, showing placement of the pigs. The arrow indicates the head of the animal. The stairway was oriented toward GZ. Direct thermal radiation occurred at X on the landing since the top of the tower was on a line of sight from this position.

The other animals were on the floor. Their positions were indicated by available space, i.e., that not being used for the experiments of Program 33, which, of course, had priority in this test.

[redacted]

Chapter 7

RESULTS

On recovery, pig 7 was found dead. It had suffered tertiary blast effects sufficient to crush one side of the chest wall. It is difficult to evaluate burn severity by inspection of a dead animal; therefore this animal was returned to the laboratory for skin biopsy and autopsy. Subsequent study of the sections of skin showed complete epidermal damage with 0.1 mm penetration of the burn into the dermis.

Pig 5, which faced the door, was inactive and appeared shocked. There were severe carbonized burns of the forehead, face, and ears. Because of its poor condition this animal was taken to the laboratory for observation in a separate cage. All other animals appeared to be in good enough condition to be removed to the pens. It is notable, however, that these animals, although grossly unharmed, displayed a marked and atypical lassitude which persisted at least through H + 15 hr. They could be approached, touched, and even picked up without making efforts to escape or vocal complaint which is usual with this species. By H + 24 hr this lassitude was no longer noticeable.

Burn severity can best be judged at the end of the first 24-hr period after injury. Animals 1, 3, 4, 6, 8, and 9 were each examined by two observers. There were no serious lesions. A few animals had mild skin irritation of the flanks from the harness. Pigs 3, 6, and 9 had questionable areas of 1st-degree burns on their chest wall. These pigs were isolated and reexamined by three observers. It was agreed that animals 6 and 9 had no burns. There was a questionable area of erythema about 1 in. in diameter on the side of pig 3 which could have been from a minimal burn or mild harness irritation. This area was biopsied. The microscopic section showed no burn.

Pig 5 was the most interesting of all. After 24 hr it was still lethargic but would stand, walk, and eat. It should be recalled that this animal was positioned to face the door and was about 3 ft from it. Severe carbonized burns were present on face, forehead, and the tops of

Fig. 7.1--Pig 5, showing the carbonized burn of the face and forehead, with singeing of the hair on the shoulders.

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the ears. Less severe lesions were found on the shoulders. The hair of the snout, front legs, and interscapular region, which had not been clipped, was singed. This animal is shown in Fig. 7.1. It was sacrificed at H + 29 hr, and skin biopsies were taken from the forehead, left ear, and left shoulder. At autopsy there were no fractures, nor was there intracranial injury. Moderately severe blast damage with gross hemorrhage was found in the lungs.

It is interesting to observe that the thermal burns of this animal were only on surfaces that were oriented toward the doorway. They were "profile" in type, and whatever caused the burn came directly at the animal in a horizontal direction from the door. The rump and flanks were uninjured; thus damaging thermal energy did not angle in from above or from the side.

Subsequent study of the microscopic sections on pig 5 showed severe, complete epidermal damage with penetration of the burn 0.3 mm into the dermis on the biopsy taken from the face. Sections from the ear and shoulder showed burns limited to the epidermis.

Chapter 8

DISCUSSION

None of the 3 pigs in the slow-fill side were burned, not even the one directly beneath the escape shaft. The walls of this shaft were painted white, but it had a perforated metal manhole type casting at its top which would not only reduce air intake but also partly screen the shaft wall from radiant thermal energy. The negative result of the experiments in the slow-fill side are valuable in showing circumstances in which thermal burns do not occur. Hence, it is here that a controlled experiment could best be carried out to alter the rate of air inflow or the amount of reflected radiant thermal energy in order to evaluate the role of each in the etiology of these burns.

The results from the experiment in the fast-fill side give convincing proof that severe thermal burns can occur in shelters. The observations on pig 5, which was just within the door, were worth our entire effort. Obviously in facing the doorway this animal was looking at the source of the thermal energy that caused the profile burns. The big question is the source of the heat.

This question demands further study. Shelters are designed to give protection, and it is evident now that this must include protection against thermal burns.

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Chapter 9

SUMMARY AND CONCLUSIONS

1. Eight young Chester White pigs were placed in a shelter used by Program 33 at shot Galileo. These animals are very well documented receivers for biological evaluation of skin burns.

2. Three pigs in the slow-fill room had no discernable burns.

3. Three pigs away from the door of the fast-fill side were not burned.

4. Two pigs were severely injured. One, which was about 3 ft inside the door of the shelter, sustained carbonized burns of those parts which were oriented toward the doorway. The other one, which was on the landing at the foot of the stairs outside the door, was killed by blast injuries. Biopsy of its skin showed it to be burned.

5. It is necessary to carry out further experimentation on the cause of these thermal burns within shelters in order to guard against them.

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